

# Entrada Play

(USGS 2204)

## General Characteristics

The Entrada play in the southeastern part of the San Juan Basin, is based on relict dune topography on top of the eolian Middle Jurassic Entrada Sandstone, associated with organic-rich limestone source rocks and anhydrite in the overlying Todilto Limestone Member of the Wanakah Formation. North of the present producing area, in the deeper, northeastern part of the San Juan Basin, porosity in the Entrada decreases rapidly. Compaction and silica cement make the Entrada very tight below a depth of 9,000 ft. No eolian sandstone buildups have been found south and west of the producing area.

**Reservoirs:** Some of the relict dunes are as thick as 100 ft, but have flanks that dip only 2 degrees. Dune reservoirs are composed of fine-grained, well-sorted sandstone, massive or horizontally bedded in the upper part, and thinly laminated, with steeply dipping cross-bedding in the lower part. Porosity (23 percent average) and permeability (370 md average) are very good throughout. Average net pay in developed fields is 23 ft.

**Source rocks:** Limestone in the Todilto Limestone Member has been identified as the source of Entrada oil. There is a reported correlation between the presence of organic material in the Todilto Limestone and the presence of the overlying Todilto anhydrite. This association limits the source rock potential of the Todilto to the deeper parts of the eastern San Juan Basin. Elsewhere in the basin, the limestone was oxygenated during deposition and much of the organic material destroyed.

**Timing and migration:** Maximum depth of burial throughout most of the San Juan Basin occurred at this time. In the eastern part of the basin, the Todilto entered the oil generation window during the Oligocene. Migration into Entrada reservoirs either locally or updip to the south probably occurred almost immediately; however, in some fields, remigration of the original accumulations has occurred subsequent to original emplacement.

**Traps:** All traps so far discovered in the Entrada Sandstone are stratigraphic and are sealed by the Todilto limestone and anhydrite. Local faulting and drape over deep-seated faults has enhanced, modified, or destroyed the potential closures of the Entrada sand ridges. Hydrodynamic tilting of oil-water contacts and (or) "base of movable oil" interfaces have had a destructive influence on the oil accumulations because the direction of tilt typically has an updip component. All fields developed to date have been at depths of 5,000–6,000 ft. Because of increase in cementation with depth, the maximum depth at which suitable reservoir quality can be found is approximately 9,000 ft.

**Exploration status and resource potential:** The initial Entrada discovery, the Media field, was made in 1953 (Gautier, et al, 1996). Development was inhibited by problems of high water cut and high pour point of the oil, problems common to all subsequent Entrada

field development. Between 1972 and 1977, seven fields similar to Media were discovered, primarily using seismic techniques. Areal sizes of fields range from 100 to 400 acres, and total estimated production of each varies from 150,000 BO to 2 MMBO. A number of areas of anomalously thick Entrada in the southeastern part of the San Juan Basin have yet to be tested, and there is a good probability that at least a few of these areas have adequate trapping conditions for undiscovered oil accumulations, but with similar development problems as the present fields. Limiting factors to the moderate future oil potential of the play include the presence of sufficient paleotopographic relief on top of the Entrada, local structural conditions, hydrodynamics, source-rock and oil migration history, and local porosity and permeability variations

## Characteristics of the Entrada Play

The Entrada Play does not yet produce in the Southern Ute Indian Reservation. The Entrada Sandstone and Wanakah Formation are present in the subsurface of the Reservation (Figs. SU-19 & -20).

The Entrada Formation is composed of two members, the Dewey Bridge Member and the Slick Rock Member (Condon, 1992). The Dewey Bridge member is 25-35 feet thick in the western side of the Reservation; it pinches out eastward. The Dewey Bridge Member is composed of brick-red to reddish-brown, very fine grained, argillaceous sandstone and siltstone. The sediments of the Dewey Bridge were deposited in a sabkah environment that bordered the Jurassic sea, which was present to the north and west of Colorado. The Slick Rock Member consists of white, pinkish-orange, and reddish-orange, very fine to fine grained, locally medium grained sandstone. Bedding is medium to thick with alternating cosets of cross bedded and flat-bedded strata. The Slick Rock averages 70-100 feet in thickness in the subsurface of the Reservation. The sediments of the Slick Rock were deposited in an extensive area of eolian dunes and interdunes that bordered the Jurassic sea.

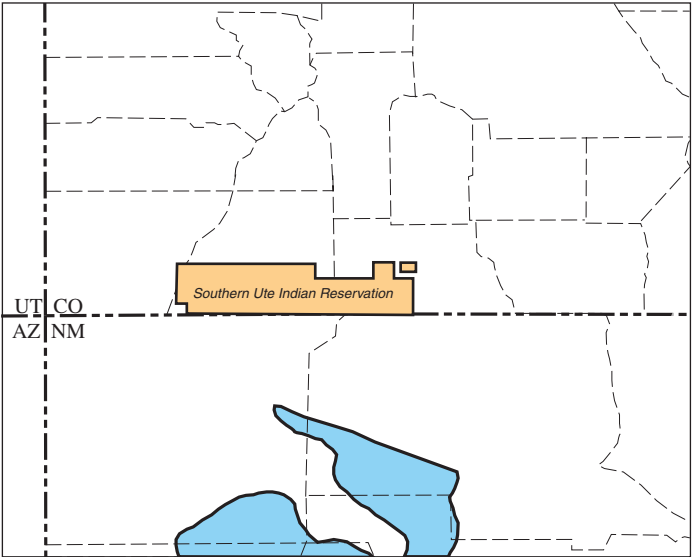


Figure SU-17. Location of the Entrada Play (modified after Gautier, Dolton, Takahashi, and Varnes, 1996).

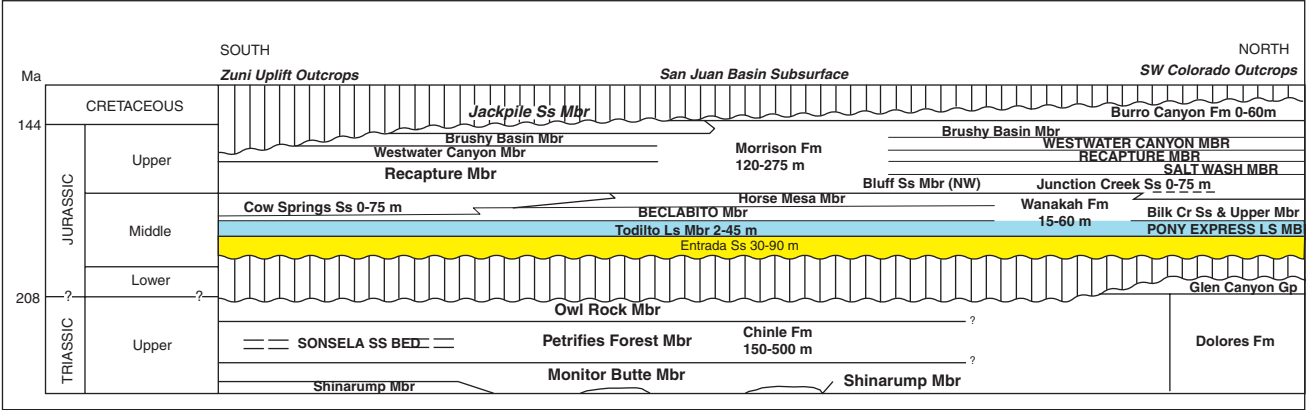


Figure SU-18. Time-stratigraphic chart of stratigraphic units on the Southern Ute Indian Reservation and adjacent areas (modified after Condon, 1992).

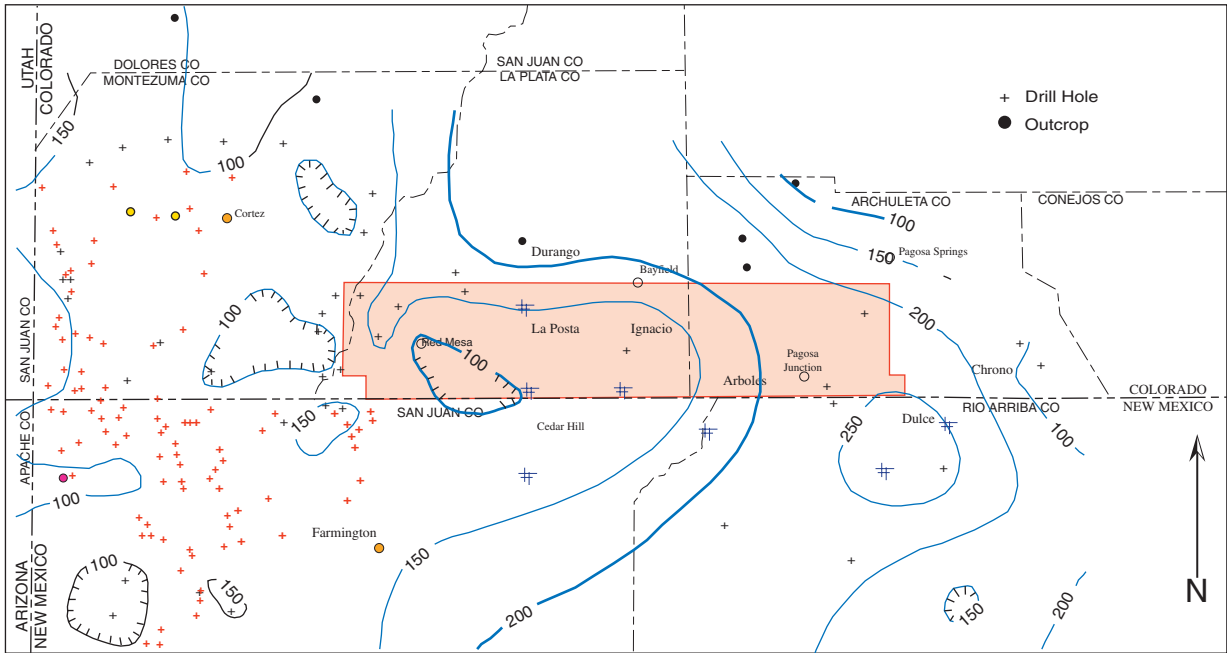


Figure SU-19. Isopach map of the Entrada Sandstone. Contour interval is 50 feet (modified after Condon, 1992).

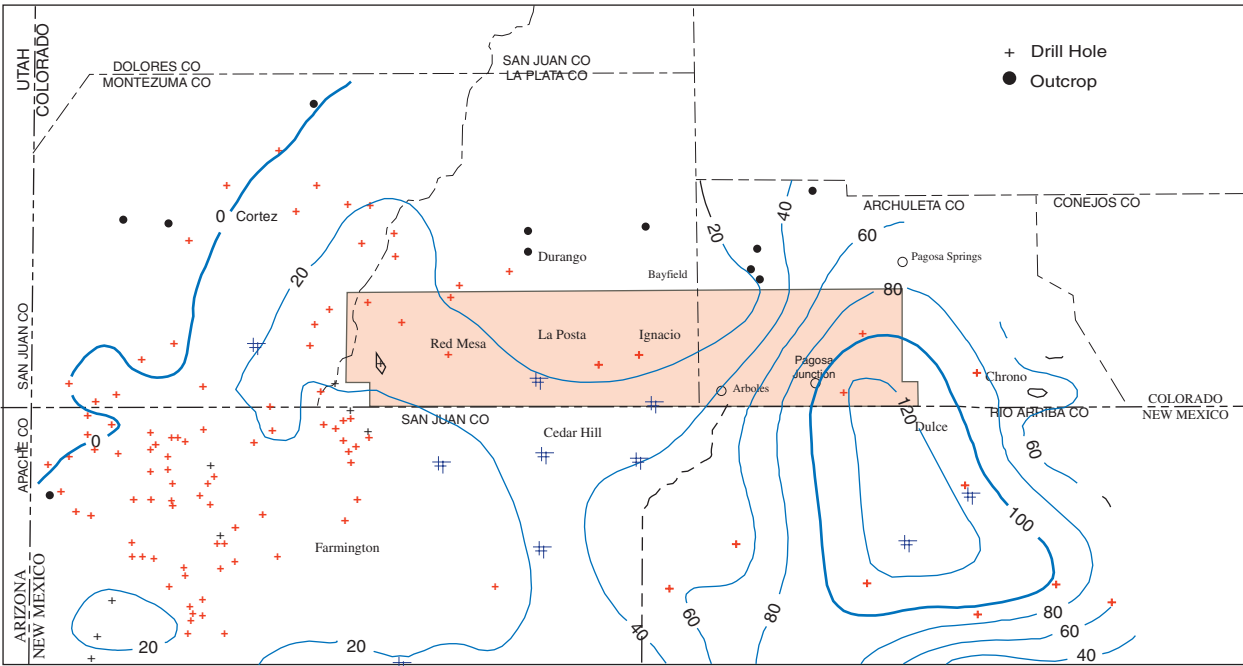


Figure SU-20. Isopach map of the Todilto Limestone Member of the Wanakah Formation and Equivalent rocks. Contour interval is 20 feet (modified after Condon, 1992).

# Basin Margin Dakota Oil Play

(USGS 2206)

## General Characteristics

The Basin Margin Dakota Oil Play is both a structural and stratigraphic play on the northern, southern, and western sides of the central San Juan Basin. Because of the variability of depositional environments in the Dakota Sandstone, it is difficult to characterize a typical reservoir lithology. Most production has been from the upper marine part of the interval, but significant amounts of both oil and gas also have been produced from the nonmarine section.

**Reservoirs:** The Late Cretaceous Dakota Sandstone varies from dominantly nonmarine channel deposits and interbedded coal and conglomerate in the northwest to dominantly shallow marine, commonly burrowed deposits in the southeast. Net pay thicknesses range from 10 to 100 ft; porosities are as high as 20 percent and permeabilities are as high as 400 md.

**Source rocks:** Along the southern margin of the play, the Cretaceous marine Mancos Shale was the source of the Dakota oil. API gravities range from 44° to 59°. On the Four Corners Platform to the west, nonmarine source rocks of the Menefee Formation were identified as the source. The stratigraphically higher Menefee is brought into close proximity with the Dakota across the Hogback monocline.

**Timing and migration:** Depending on location, the Dakota Sandstone and lower Mancos Shale entered the oil window during Oligocene to Miocene. In the southern part of the area, migration was still taking place in the late Miocene time or even more recently.

**Traps:** Fields range in size from 40 to 10,000 acres and most production is from fields of 100-2,000 acres. Stratigraphic traps are

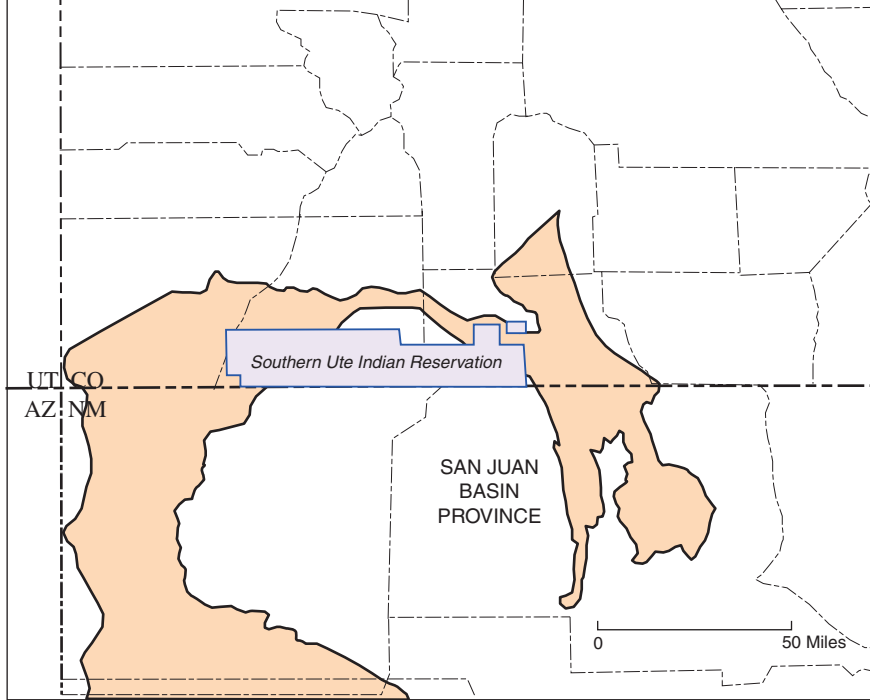


Figure SU-22. Location of the Basin Margin Dakota Oil Play (modified after Gautier, et al., 1996).

typically formed by updip pinchout of porous sandstone into shale or coal. Structural traps on faulted anticlines sealed by shale form some of the larger fields in the play. Oil production ranges in depth from 1,000 to 3,000 ft.

**Exploration status and resource potential:** The first discoveries in the Dakota play were made in the early 1920's on small anticlinal structures on the Four Corners Platform. Approximately 30 percent of the oil fields have an estimated total production exceeding 1 MMBO, and the largest field (Price Gramps) has production of 7 MMBO. Future Dakota oil discoveries are likely as basin structure and Dakota depositional patterns are more fully understood.

## The Basin Margin Dakota Oil Play

The Dakota Sandstone is a coastal plain deposit laid down in front of the advancing Mancos Sea. The oldest unit of the Dakota Sandstone on the Southern Ute Indian Reservation is the lower Cenomanian Encinal Canyon Member (Fig. SU-24). It consists of alluvial deposits that fill the valleys at the sub-Dakota unconformity. It was deposited by aggradation of Dakota streams in response to rising base level during the earliest stages of the T-1 transgression.

The Encinal Canyon Member is characteristically a trough-cross bedded, fine- to medium-grained sandstone that is commonly conglomeratic at its base. Tabular-planar crossbeds and, more rarely, horizontal or low-angle laminations also occur at some locations. The Encinal Canyon member is overlain by delta-plain deposits in the Four Corners and Durango areas, by shore-zone deposits in the Coldwater Creek and Durango areas (north of the Reservation on the eastern side), and by marine deposits in northwestern New Mexico.

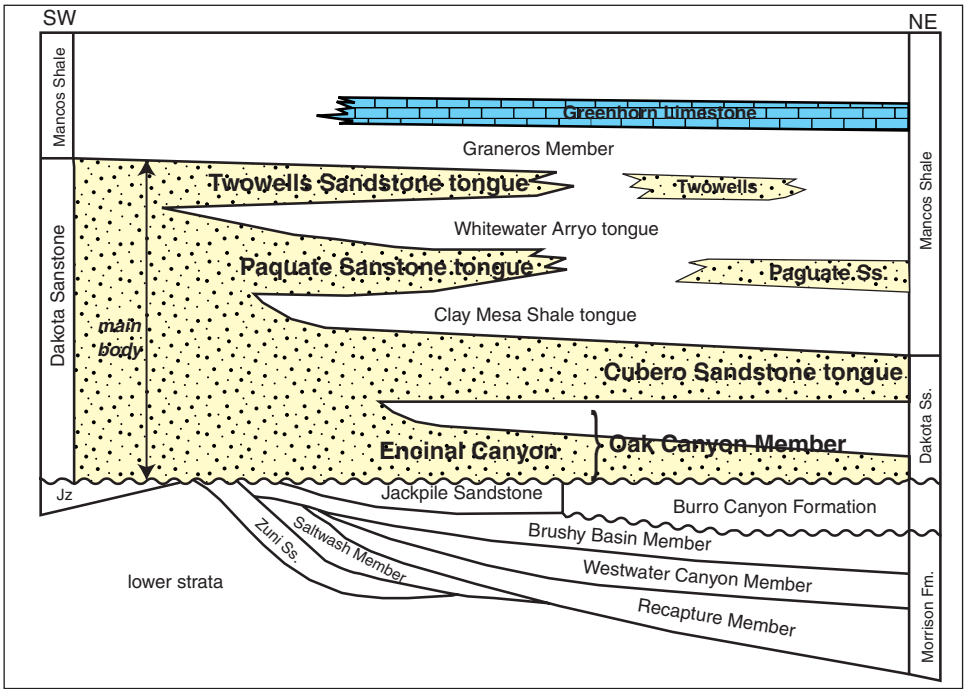


Figure SU-23. Southwest - northeast schematic stratigraphic cross section relating members of the Dakota Sandstone and Mancos Shale and adjacent units in the San Juan Basin (modified after Whitehead, 1993).

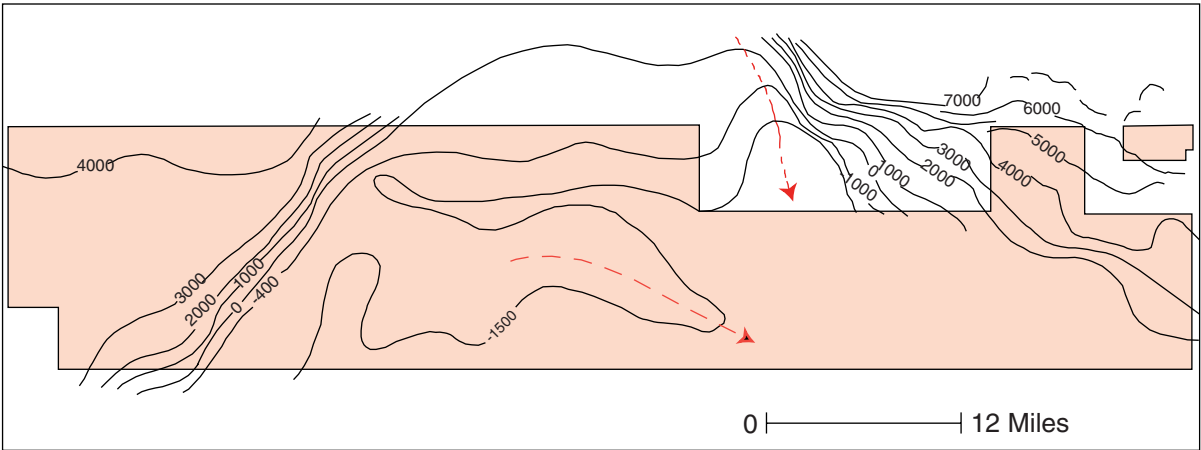


Figure SU-21. Structure contour map of the base of the Dakota Sandstone in the Southern Ute Indian Reservation. Contour interval is 1000 feet except for -1500 foot contour. Southeastern part of the Reservation has no data (modified after Andersen, 1992).

This distribution of depositional environments is consistent with shoreline trends (Fig.25). North-south shoreline trends suggest that depositional environments in the subsurface on the Reservation are similar to those in the Durango and Coldwater Creek areas north of the Reservation.

The shore-zone deposits that overly the Encinal Canyon Member in the Coldwater Creek and Durango areas are composed of fine grained, bioturbated, and flat-bedded or ripple-laminated sandstone probably deposited in tidal-flat, shoreface, or offshore-bar environments. Coal may have been deposited in coastal swamps, and siltstone and mudstone may represent lagoonal or offshore environ-

ments. Deltaic rocks on the western part of the Reservation and shore-zone rocks in the eastern part are probably lateral equivalents, deposited during a stillstand of the shoreline. The Dakota is a transgressive unit in the Reservation area; the fluvial rocks of the Encinal Canyon are overlain by deltaic rocks and shore zone rocks that are, in turn, overlain by the marine Mancos Shale.

Reservoirs on the Dakota Sandstone are controlled by stratigraphic and structural trapping. Successful exploration for lower Dakota Sandstone production is obtained by careful mapping of channel sandstones and close attention to oil and gas shows in the thin, porous sandstone that may develop in channels.

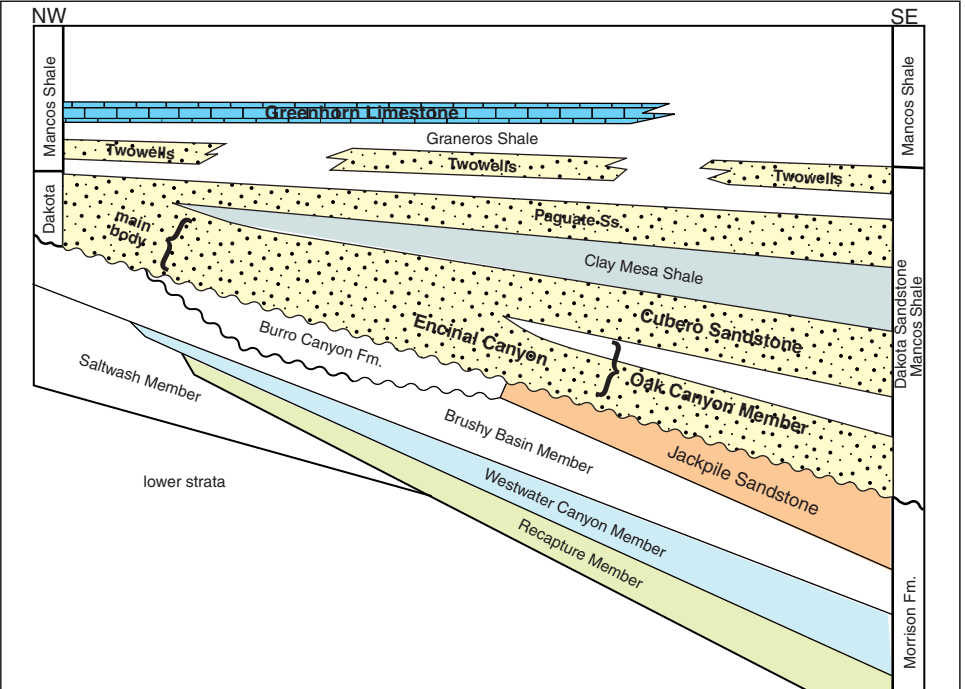
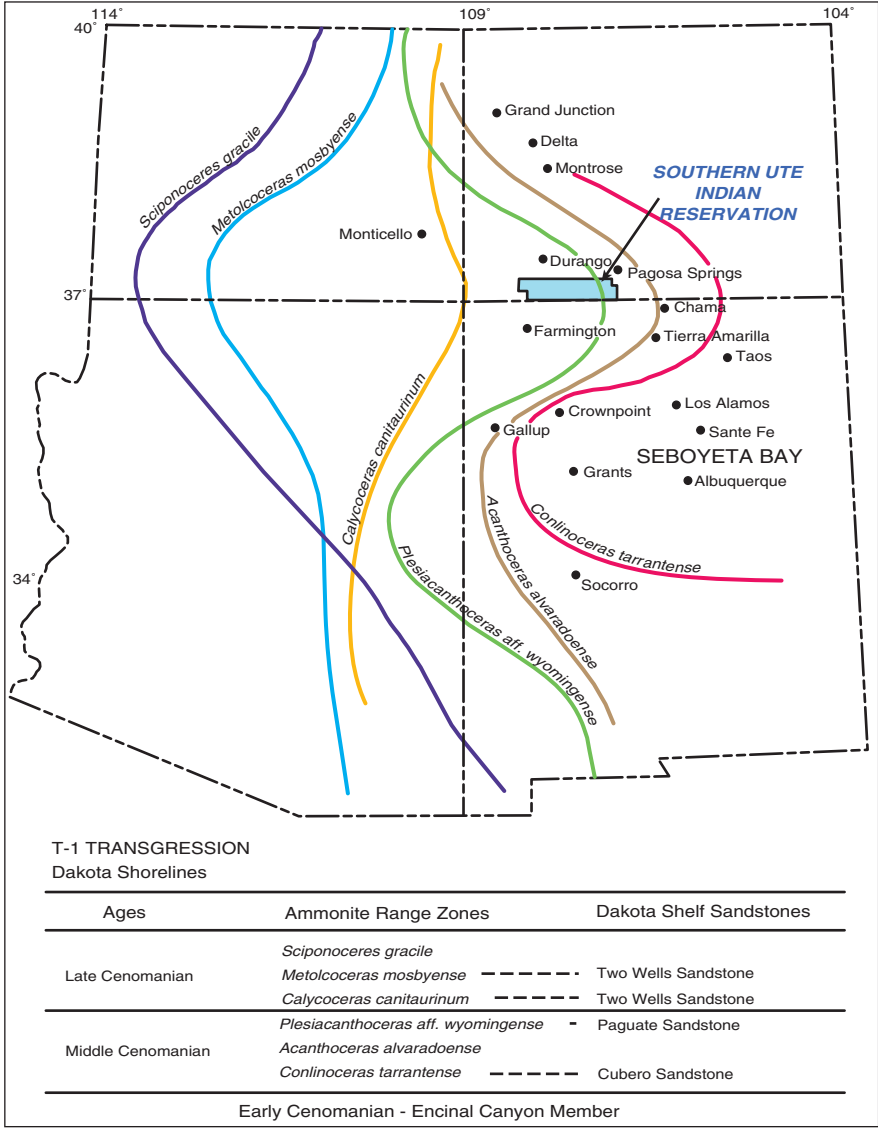
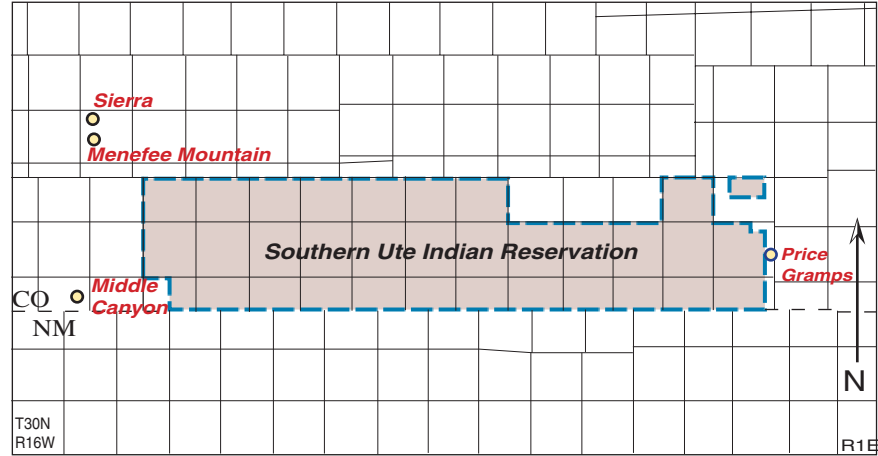


Figure SU-24. Northwest - southeast schematic stratigraphic cross section relating members of the Dakota Sandstone and Mancos Shale and adjacent units in the San Juan Basin (modified after Whitehead, 1993).



**Figure SU-25.** Map showing positions of the western shoreline of the Western Interior Seaway during deposition of the upper part of the Dakota Sandstone during the middle and late Cenomanian. Shoreline trends are based on the distribution of ammonite fossils found in the lower part of the Mancos Shale, which interfingers with the Dakota Sandstone (modified after Aubrey, 1991).



**Figure SU-26.** Location of oil and gas field discovery wells for fields producing from the Basin Margin Dakota Oil Play.

### Analog Fields In and Near Reservation

(\*) denotes field lies within the reservation boundaries

**Price Gramps**  
(see figure SU-27)

Location of discovery well: SE, SE, sec24, T33N, R2E (1935)  
Producing formation: Cretaceous Dakota Sandstone  
Type of trap: Faulted asymmetric anticline  
Number of producing wells: 24 (1977)  
Initial production: 217 BOD  
Cumulative Production: 6, 716,434 BO (1992)  
Oil characteristics: c, 60° pour point  
Type of drive: Partial water drive  
Average net pay: 30 feet  
Porosity: 14.6 % ave., 4% min., 21.1% max.  
Permeability: 100 mD

**Middle Canyon Dakota**

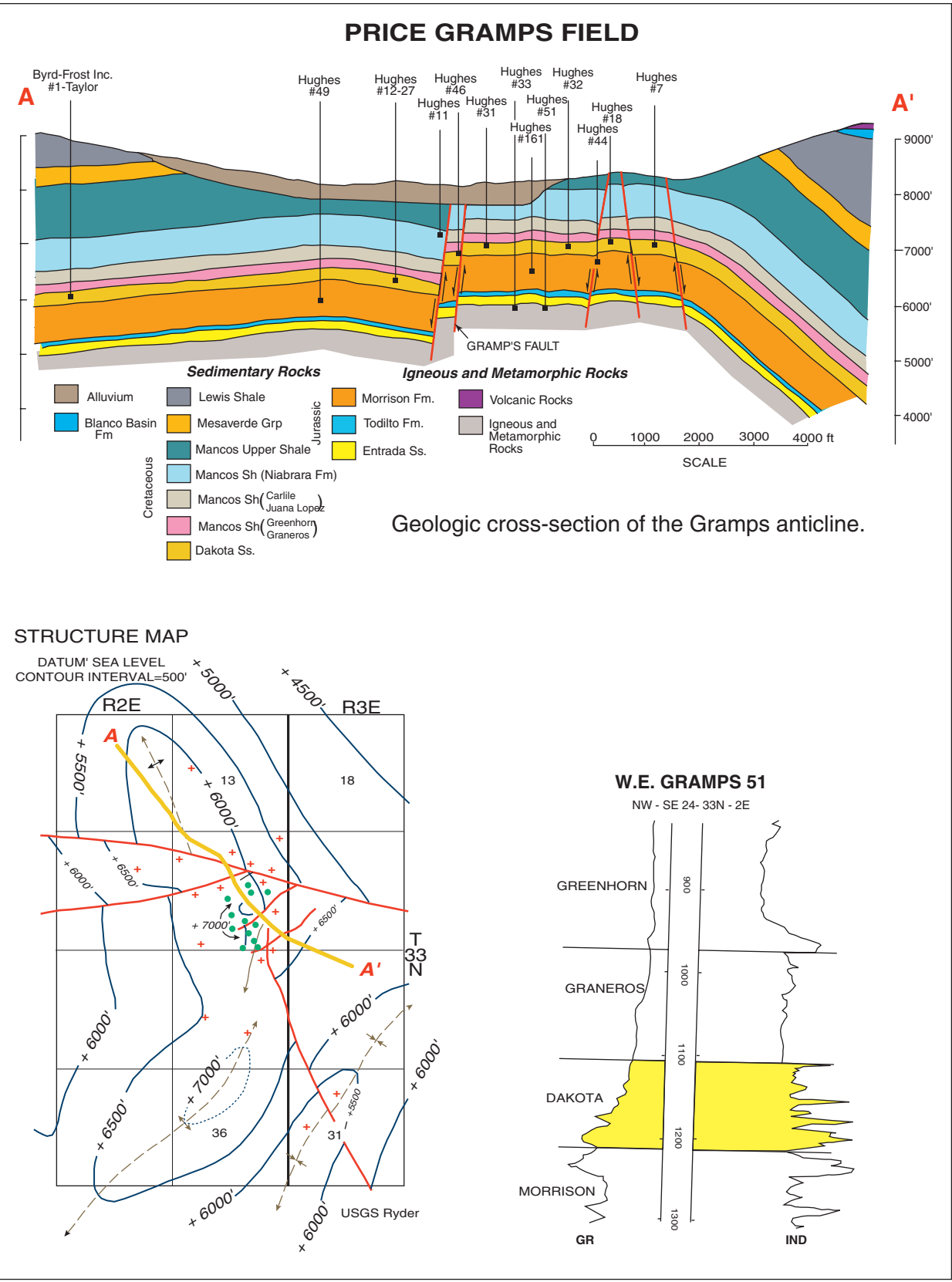
Location of discovery well: NE, SW, sec 14, T32N, R15W (1969)  
Producing formation: Cretaceous Dakota Sandstone  
Type of trap: Stratigraphic  
Number of producing wells: 1 (1977)  
Initial production: 122.64 BOD, 7BWD  
Cumulative Production: 4886 BO (1977)  
Oil characteristics: N/A  
Type of drive: Water drive  
Average net pay: 20 feet  
Porosity: 12.1% ave.  
Permeability: 0.30 mD ave.

**Sierra**

Location of discovery well: SE, NW, sec 5, T35N, R13W (1957)  
Producing formation: Cretaceous Dakota Sandstone  
Type of trap: Stratigraphic  
Number of producing wells: 12 (1992)  
Initial production: 969 MCFGD  
Cumulative Production: 1,299,016 BO (1992), 29,021 MCFG  
Oil characteristics: 35° API gravity  
Type of drive: solution gas, downdip water encroachment  
Average net pay: 22 feet  
Porosity: 18-20%  
Permeability: 700 mD

**Menefee Mountain**

Location of discovery well: NW, NE, NW, sec 16, T35N, R13W  
Producing formation: Cretaceous Dakota Sandstone  
Type of trap: Structural, stratigraphic  
Number of producing wells: 3 (1983)  
Initial production: 26 BOD, 11 BWD  
Cumulative Production: 49,230 BO, 255 MCFG (1992)  
Oil characteristics: 34.0° API gravity  
Type of drive: water  
Average net pay: 15 feet  
Porosity: 12-14%  
Permeability: unknown



**Figure SU-27.** Structural cross section, structure contour map, and type log for the Price Gramps Field (modified after Donovan, 1978).

# Tocito-Gallup Sandstone Oil Play

(USGS 2207)

## General Characteristics

The Tocito-Gallup Sandstone Oil Play is associated with lenticular sandstone bodies of the Upper Cretaceous Gallup Sandstone and Tocito Sandstone Lenticle, and Mancos Shale source rocks lying immediately above an unconformity. The play covers almost the entire area of the province. Most of the producing fields are stratigraphic traps along a northwest-trending belt near the southern margin of the central part of the San Juan Basin. Almost all production has been from the Tocito Sandstone Lenticle of the Mancos Shale and the Torrivio Member of the Gallup Sandstone.

**Reservoirs:** The Tocito Sandstone Lenticle of the Mancos Shale is the major oil producing reservoir in the San Juan Basin. The name is applied to a number of lenticular sandstone bodies, commonly less than 50 ft thick, that lie on or just above an unconformity and are of undetermined origin. Reservoir porosities in producing fields range from 4 to 20% and average about 15%. Permeabilities range from 0.5 to 150 md and are typically 5 to 100 md. The only significant production from the regressive Gallup Sandstone is from the Torrivio Member, a lenticular fluvial channel sandstone lying above, and in some places scouring into the top of the main marine Gallup Sandstone.

**Source rocks:** Source beds for Gallup oil are the marine Upper Cretaceous Mancos Shale. The Mancos contains 1-3 weight percent organic carbon and produces a sweet, low-sulfur, paraffin-base oil that ranges from 38° to 43° API gravity in the Tocito fields and from 24° to 32° API gravity farther to the south in the Hospah and Hospah South fields.

**Timing and migration:** The upper Mancos Shale of the central part of the San Juan Basin entered the thermal zone of oil generation in

late Eocene time and gas generation in Oligocene time. Migration updip to reservoirs in the Tocito Sandstone Lenticle and regressive Gallup followed pathways similar to those determined by present structure because basin configuration has changed little since that time.

**Traps:** Almost all Gallup production is from stratigraphic traps at depths between 1,500 and 5,500 ft. Hospah and Hospah South, the largest fields in the regressive Gallup Sandstone, are combination stratigraphic and structural traps. The Tocito sandstone stratigraphic traps are sealed by, encased in, and intertongue with the marine Mancos Shale. Similarly, the fluvial channel Torrivio Member of the Gallup is encased in and intertongues with finer grained, organic-rich coastal-plain shales.

**Exploration status and resource potential:** Initial Gallup field discoveries were made in the mid 1920's; however, the major discoveries were not made until the late 1950's and early 1960's in the deeper Tocito fields, the largest of which, Bisti, covers 37,500 acres and has estimated total ultimate recovery of 51 MMBO. Gallup producing fields are typically 1,000 to 10,000 acres in area and have 15 to 30 ft of pay. About one-third of these fields have an estimated cumulative production exceeding 1 MMBO and 1 BCF of associated gas. All of the larger fields produce from the Tocito Sandstone Lenticle of the Mancos Shale and are stratigraphically controlled. South of the zone of sandstone buildups of the Tocito, the regressive Gallup Sandstone produces primarily from the fluvial channel sandstone of the Torrivio Member. The only large fields producing from the Torrivio are the Hospah and Hospah South fields, which are combination traps. Similar, undiscovered traps of small size may be present in the southern half of the basin. The future potential for oil and gas is thought to be low to moderate.

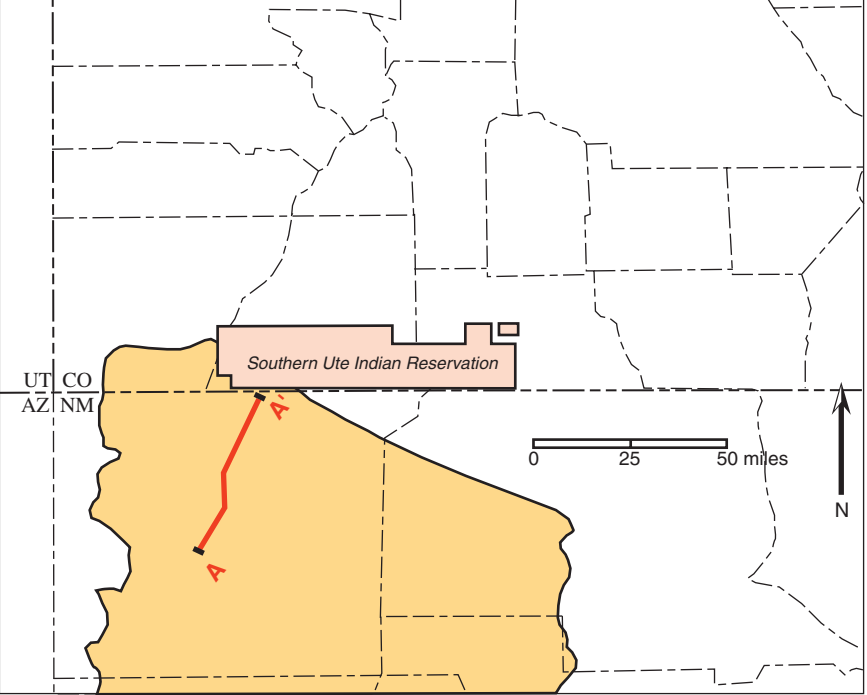
## Characteristics of the Tocito-Gallup Oil Play

In recent years a sequence stratigraphic framework has been applied to the Tocito and Gallup Sandstones near the Southern Ute Indian Reservation (Fig. SU-30). This framework helps explain hydrocarbon occurrence and the stratigraphic traps associated with these units. The northern extent of the Gallup Sandstone production is several miles south of the Indian reservation where the unit is truncated by the Tocito Sandstone. For this reason, the Gallup Sandstone will not be included in the following description.

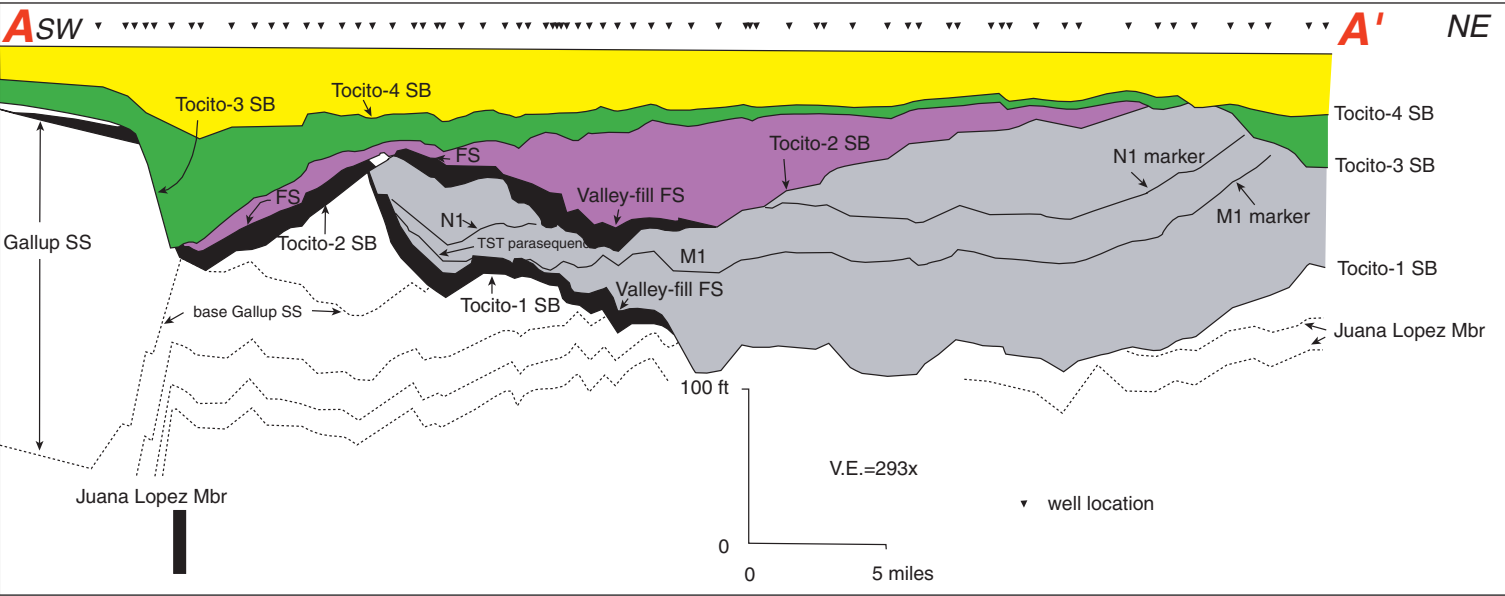
Since the late 1950's, 130 MMBOE have been produced from the Tocito. The Tocito Sandstone marks a significant change from shoreface/coastal plain depositional systems which prevailed throughout Gallup deposition. The Tocito Sandstone is a transgressive sequence set internally composed of four high-frequency sequences. In ascending order, they are Tocito-1, Tocito-2, Tocito-3 and Tocito-4 (Fig. SU-30). In the subsurface, the Tocito is distributed into narrow and elongate bodies which trend northwest-southeast (Figs. SU-31 and SU-32). Isopach maps of the Tocito units show that the Tocito-3 and Tocito-4 are the only units beneath the southern Ute Indian Reservation.

The high-frequency sequences of the Tocito Sandstone contain the lowstand, transgressive, and usually highstand systems tracts. There are sequence boundaries at the base of each high-frequency sequence represented by irregular erosional surfaces that truncate into the underlying units. Above the erosional surfaces are incised valley fill deposits representing the lowstand systems tracts. The top of the valley fills represent transgressive flooding surfaces and the passage from valley-filling sedimentation to open-marine/shelfal sedimentation and the onset of the transgressive systems tracts. The transgressive systems tracts are overlain by distal marine shales of the highstand systems tracts (Tocito-1 and Tocito-2 only). Due to their close vertical juxtaposition, the four Tocito sequences are collectively interpreted as components of a sequence set. The four sequences are thought to reflect higher-order cycles in relative sea level which were superimposed on a longer term cycle.

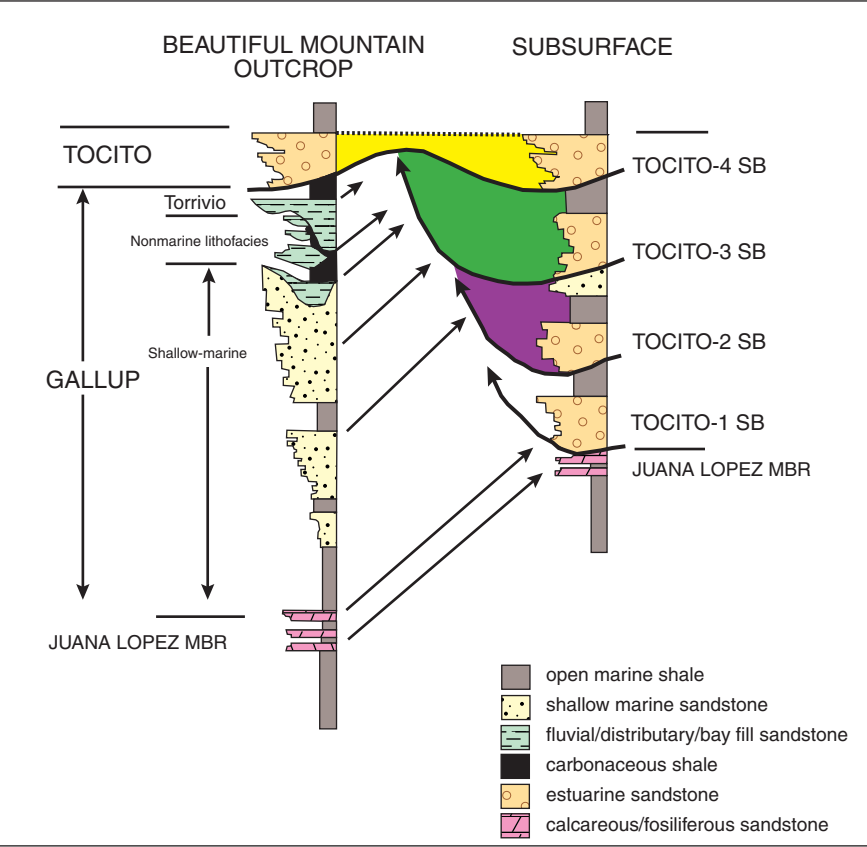
The hydrocarbon trapping is the result of stratigraphic relationships. Structural dip is uniformly toward the northeast and consequently provides only minor influence on the pooling of hydrocarbons. The four main trapping elements are: truncation by younger sequence boundary, arcuate bends in valleys, up-dip valley termination, and



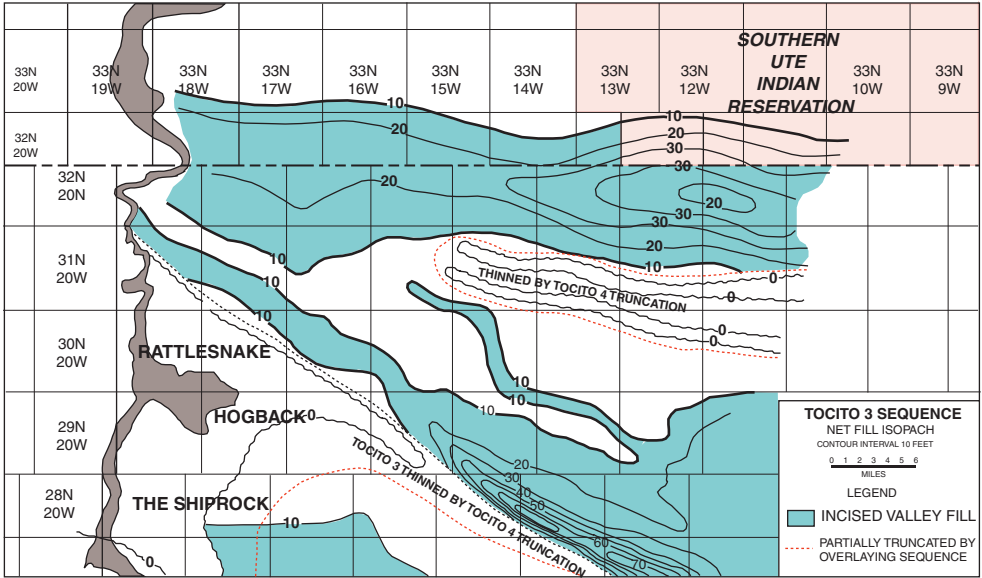
**Figure SU-29.** Location of the Tocito-Gallup Sandstone Oil Play. Cross section A-A' is shown in Fig. SU-28. (modified after Gautier, et al., 1996).



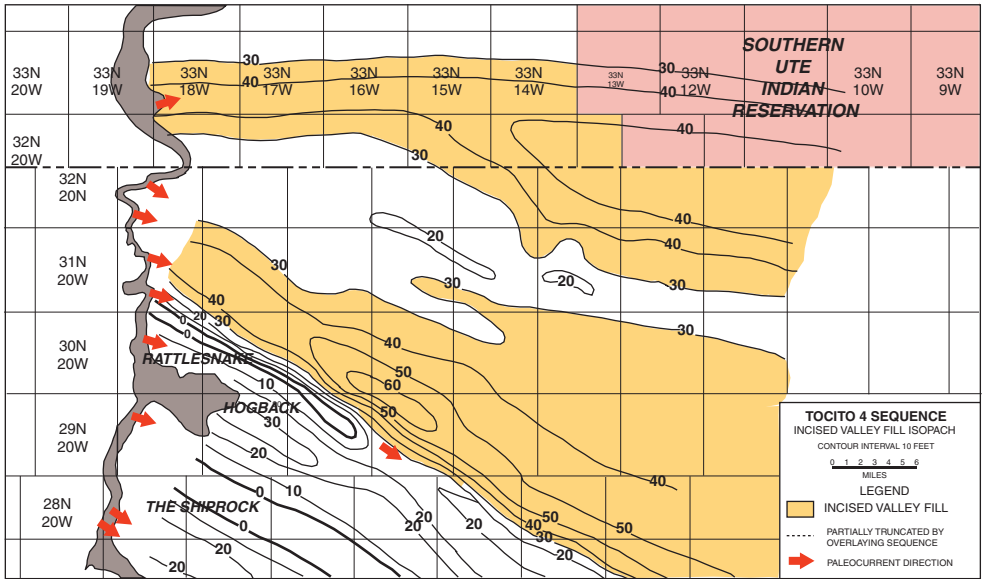
**Figure SU-28.** Detailed regional cross section showing high-resolution stratal geometries defined by the key stratigraphic surfaces of the Tocito Sandstone. Position of the cross section is shown in Fig. SU-29 (modified after Jennette and Jones, 1995).



**Figure SU-30.** Composite stratigraphic summary comparing the outcrop and the subsurface expression of the Gallup and Tocito interval (modified after Jennette and Jones, 1995).



**Figure SU-31.** Isopach map and cross section of the Tocito-3 sequence. The contoured interval of the Isopach Map is the Tocito-3 sequence boundary to the Tocito-4 sequence boundary. Interval thickness of ten feet and greater is highlighted. The cross section is a transverse section across the Tocito-3 Waterflow Valley (modified after Jennette and Jones, 1995).



**Figure SU-32.** Isopach map and cross section of the Tocito-4 sequence. The contoured interval of the Isopach Map is the Tocito-4 sequence boundary to the overlying flooding surface. Interval thickness of thirty feet and greater is highlighted. The cross section is a transverse section across the Tocito-4 Rattlesnake Valley (modified after Jennette and Jones, 1995).

## Analog Fields In and Near Reservation

(\*) denotes field lies within the reservation boundaries

### Albino Gallup (see figure SU-34)

Location of discovery well: NC, NE, sec 26, T32N, R8W (1974)  
 Producing formation: Gallup sandstone of the Mancos Shale  
 Type of trap: Structural, Stratigraphic  
 Number of producing wells: 1 (1994)  
 Initial production: 2.9 MMCFGD  
 Cumulative Production: 254,377 MCFG (1994)  
 Gas characteristics: N/A  
 Type of drive: Gas expansion  
 Average net pay: up to 900 feet of fractured interval  
 Porosity: 3-8%, and fractures  
 Permeability: fracture permeability

### Cinder Buttes

SE, SE, SW, sec 13, T32N, R12W (1966)  
 Producing formation: Cretaceous Gallup Sandstone  
 Type of trap: Fractured sandstone, structural-stratigraphic  
 Number of producing wells: 3 (1987)  
 Initial production: 302 MCFGD  
 Cumulative Production: 42,130 MCFG (shut in 1987)  
 Gas characteristics: 1,176 BTU  
 Type of drive: Depletion  
 Average net pay: 30 feet (divided among 6-8 thin sandstone beds)  
 Porosity: 16% estimated  
 Permeability: unknown

### Verde Gallup

SE, SE, sec 14, T31N, R15W (1955)  
 Producing formation: Fractured interval, Cret. Gallup Sandstone  
 Type of trap: Fractured shale, stratigraphic  
 Number of producing wells: 27 (1977)  
 Initial production: 180 BOD  
 Cumulative Production: 7,963,004 BO, 174,956 MCFG (1994)  
 Oil characteristics: 38° -42° API gravity  
 Gas characteristics: sweet high BTU  
 Type of drive: Gravity drainage  
 Average net pay: Variable  
 Porosity: Fracture  
 Permeability: Unknown

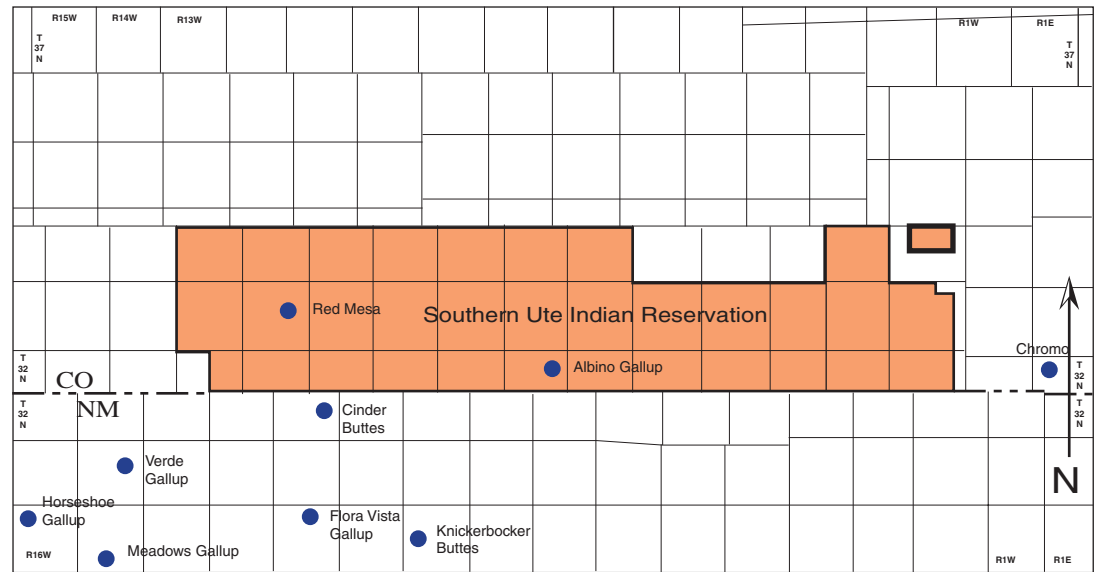
### Flora Vista Gallup

SE, SW, sec 2, T30N, R12W (1961)  
 Producing formation: Cretaceous Gallup Sandstone  
 Type of trap: Stratigraphic  
 Number of producing wells: 3 (1977)  
 Initial production: 1,070 MCFGD  
 Cumulative Production: 11,114,501 MCFG, 133,026 B condensate (1994)  
 Oil characteristics: BTU 1,303  
 Type of drive: Solution gas  
 Average net pay: 9 feet  
 Porosity: 9-12%, 10% ave. (sonic log calculated)  
 Permeability: unknown

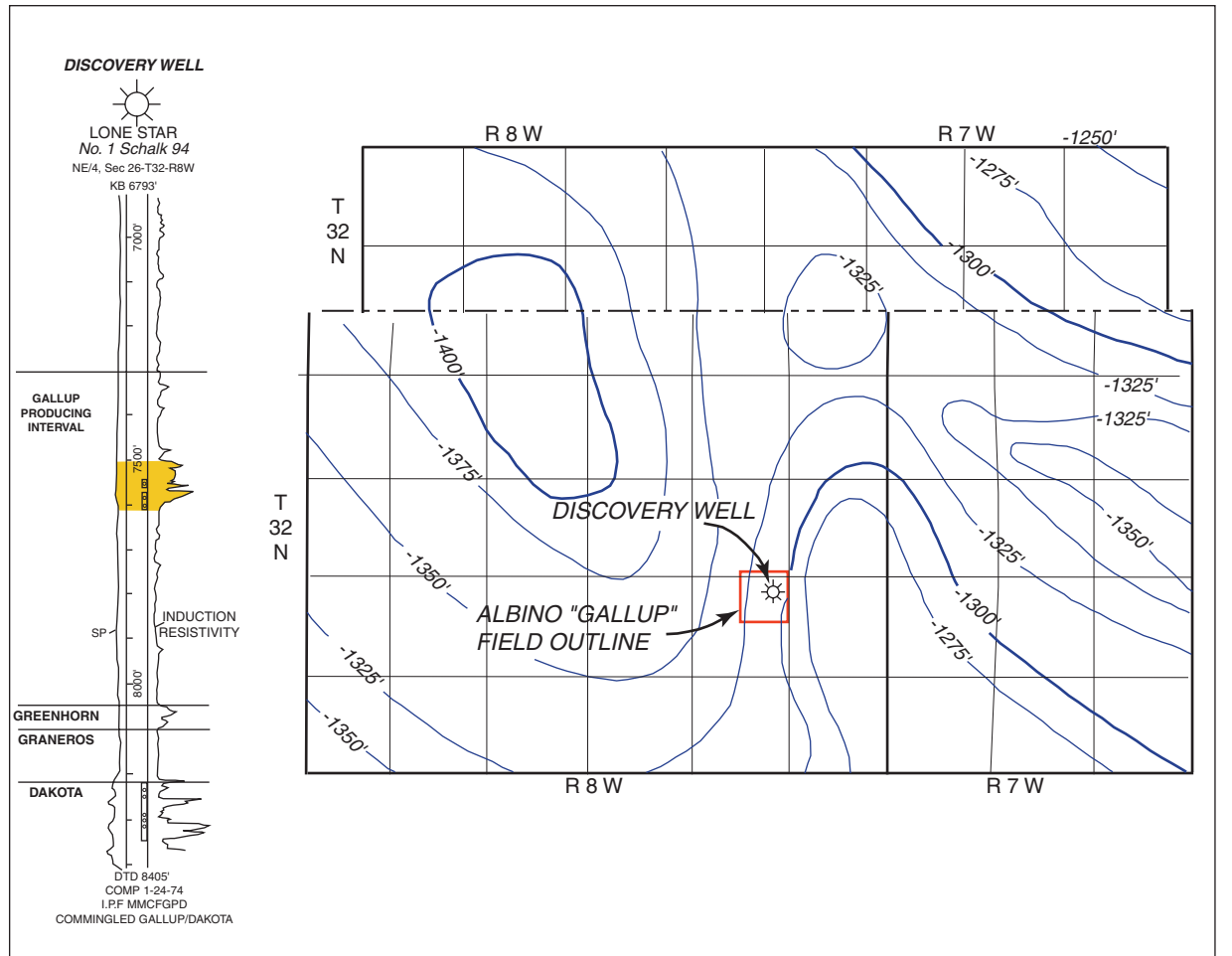
\*Red Mesa (poor historical data)

\*Chromo (poor historical data)

(Fassett, 1978,1983; Wells and Lay, 1997)



**Figure SU-33.** Location of oil and gas field discovery wells for fields producing from the Tocito-Gallup Sandstone Oil Play.



**Figure SU-34.** Structure contour map, and type log from Albino Gallup Field (modified after Middleman, 1983).